Although the several concepts expressed appear to be those most warranted by the data, most of them are tentative. Certainly it is venturesome to infer from a mere three recoveries the existence of a Pacific coast migration route. The most likely source of error is the predominance of juvenile-banded recoveries. This does not apply to the Cape group where probably one-third of the living adults carry bands and an average of two-thirds of the young are banded yearly; but elsewhere the coverage, rather sporadic and superficial, has by-passed the adults. Assuredly the efforts of this Station to make knowledge of the Common Tern more extensive and always correct can succeed only when it has been supplemented by the duplicating work of other banders elsewhere, by banding chicks particularly in the many colonies that have yet to be banded, and more than all else by trapping the adults. Repeatedly in this study group adherence and site tenacity have provided the most acceptable explanations for what the data have indicated. This gives additional support to the opinion that the two trends are of maximum importance in the Common Tern's behavior pattern, and even to the welfare of the species.

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THE RECORDING OF DIURNAL ACTIVITY PATTERNS IN CAGED BIRDS*

By DONALD S. FARNER and L. R. MEWALDT

INTRODUCTION

The recording of activity of caged birds may be a useful tool in a variety of problems in avian physiology and psychology. Thus far, however, primary attention has been directed toward the investigation of *Zugunruhe*, the nocturnal activity of caged nocturnal migrants during the migratory season. This phenomenon has been known for more than a century, the early published records having been summarized by von Homeyer (1881) and Wachs (1926). Apparently *Zugunruhe* was first investigated quantitatively by Wagner (1930) with five passerine species

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in Germany. Thereafter a considerable series of investigations of *Zugunruhe,* and other activity phenomena was developed in Finland by Palmgren and his associates (Palmgren, 1937, 1938, 1939b, 1944a), and in Germany by Schildmacher (1933, 1934, 1937, 1938a, b), Wagner (1936, 1937), Merkel (1937, 1938, 1940), Stadie (1938a, b), Putzig (1938a, b), and others. The investigations of *Zugunruhe* have been reviewed critically by Palmgren (1944b), and, to a lesser extent, by van Oordt (1949), Farner (1950), and Steinbacher (1951). There seems to be little doubt that, cautiously applied, the results from such investigations can be of importance in understanding several aspects of migration. Diurnal activity patterns in general have been discussed recently by Palmgren (1949). This type of experimental approach has received virtually no attention in America. Except for the rather considerable body of data obtained and now being analyzed in our laboratory, the only American investigations of this type known to us are those reported by Cook and Frederickson (1936) and those described very briefly by Eyster (1952). The latter apparently have been in progress concurrently with ours.

Apparently the first automatic recording of the activity of caged birds was that of Szymanski (1914, 1916) who used the traditional tambour system to transmit movements of a cage to a recording stylus. However, his apparatus was unsatisfactory for recording details of the intensity of activity because of the very slow movement of the recording surface. In his pioneer experiments on *Zugunruhe,* Wagner (1930) employed a unit consisting of a cage mounted on sensitive coiled springs so that movements of the bird caused the opening and closing of a switch in an electromagnetic recording circuit. Recording was accomplished on a moving tape (1.86 meters per hour) by means of a stylus operated by the electromagnet. Stadie (1938b) suspended movable perches with coil springs, these springs being so adjusted that the weight of the bird depressed the perch sufficiently to bring a wired metallic plate on its base in contact with a metallic support. Making and breaking this contact operated an electromagnet which in turn caused the movement of a stylus on a kymograph. Merkel's (1938, 1940) ingenious apparatus involved perches so adjusted with springs that the recording circuit was closed only by the impact of the bird hitting the perch but remained open while the bird was sitting still on the perch. Each closure of the circuit was recorded by an electrical counter.

The investigations of Palmgren have employed three original types of recording apparatus. The first (Palmgren, 1935) involved a weighted wire wound about the shaft of a cogwheel with an escapement apparatus. The escapement apparatus was connected by means of a wire to the pivoted, and finely balanced, perch of the experimental cage. Each movement of the perch then permitted a unit movement of the cogwheel. The amount of movement of the bird, for a given period, could then be estimated by the length of wire unwound during that period. Obviously this did not permit the recording of the temporal pattern of activity unless measurements of the wire were made at very frequent intervals. The second apparatus developed by Palmgren (1938) was designed to record activity as a function of time. A capillary pen was mounted on a slider propelled by a clockwork mechanism at the rate of 1 cm. per hour over the surface of the recording drum, its movement being parallel to the axis of the drum. A delicately balanced spring-cog arrangement provided a unit movement of the cog on the shaft of the recording drum for each movement of the perch in the experimental cage. Palmgren's (1943a) third apparatus provided a much more usable record. In this apparatus a capillary pen inscribed continuously on a uniformly moving (1 revolution per day) recording drum with a circumference of 480 mm. The pen was mounted on a slider which moved 1 mm. in a direction parallel with the axis of the drum for each movement of the perch in the experimental cage until 30 movements were thus summated whereafter the pen returned to the base line. This summation of units made the records much easier to analyze. This apparatus was used extensively in Palmgren's laboratory with consistent success. Palmgren's ingenious recorders had, as their principal disadvantage, a totally mechanical transmission of the movement of the perch. This type of arrangement requires that the recorder be very near the experimental cage. There is a further disadvantage in that they require the fabrication of a variety of mechanical units with a considerable degree of precision.

The system employed by Cook and Frederickson (1936) required the manual depression of a key by an observer for each movement of the bird; a signal marker in the electric circuit recorded each closure of the key on a slowly moving kymograph drum. The limitations of such a system are obvious. We are not familiar with the nature of the apparatus for "mechanical recording" described briefly by Eyster (1952).

A New System for Recording Activity of Caged Birds

In our laboratory we have developed a system which has operated successfully for more than fifty thousand bird-hours of recording of the activity of caged White-crowned Sparrows, *Zonotrichia leucophrys gambelii.* Although the records are more tedious to analyze than those of the third Palmgren apparatus, the system has the advantage that the recording unit can be located remotely with respect to the experimental cages and, that it requires, for the most part, standard laboratory apparatus and readily obtainable electrical parts.

In principle, the apparatus consists of a double electrical circuit with a two-way microswitch (S) so arranged that when the bird alights on the perch, the capacitor-discharging circuit (Figure 1), which includes the signal marker (SM) and the previously charged capacitor (C), is closed. The capacitor then discharges through the signal marker which inscribes a vertical mark on the kymograph paper by means of its capillary pen. When the bird leaves the perch the microswitch closes the capacitor-charging circuit which includes the capacitor (C) and the power source. The capacitor becomes charged almost instantaneously and remains charged until the bird again alights on the perch. This type of circuit has the advantage of preventing prolonged activation of the signal marker while the bird remains on the perch. Thus is

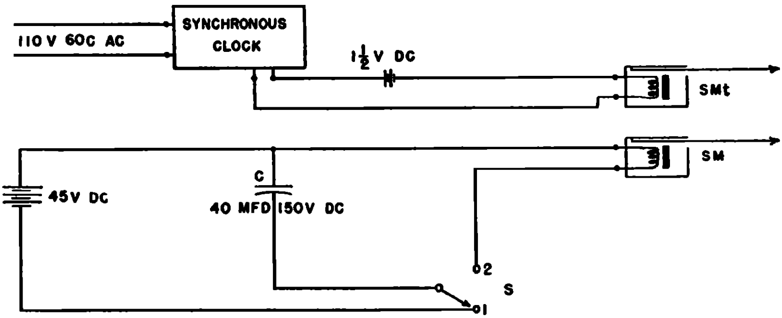

Fig. 1. Schematic diagram of circuits for recording from one activity cage.

eliminated the tendency to burn out signal-marker coils. Furthermore, the life of the dry-cell power source is consequently prolonged. In actual practice, several circuits are combined (Figure 3) for simultaneous recording from several cages (up to six in each operating unit). A signal marker (SMt) in series with a synchronous-clock timer and an appropriate current source is used to mark the kymograph paper at one-minute intervals. By use of multistrand cable it is possible to operate recording apparatus at a considerable distance from the cages. This is particularly useful when recordings are being made of caged birds under outdoor conditions.

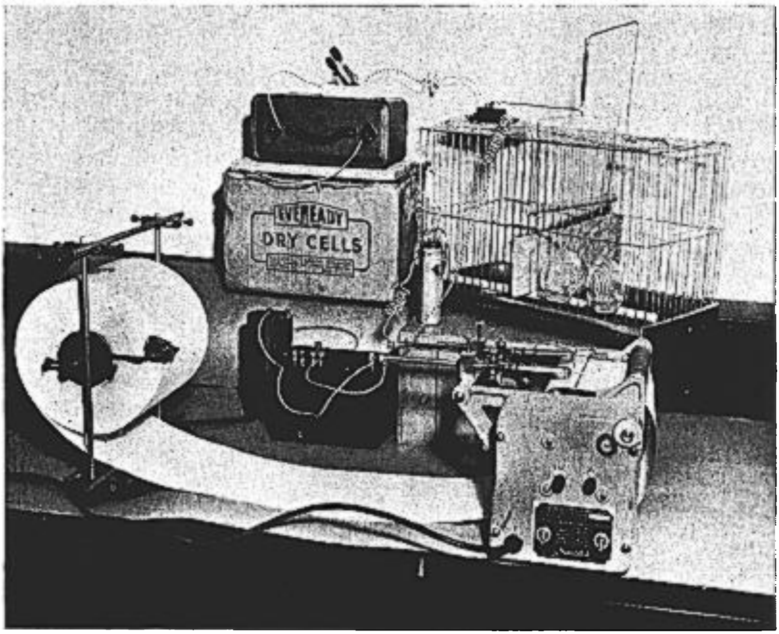

Fig. 2. Activity cage with recording unit as diagrammed in Fig. 1.

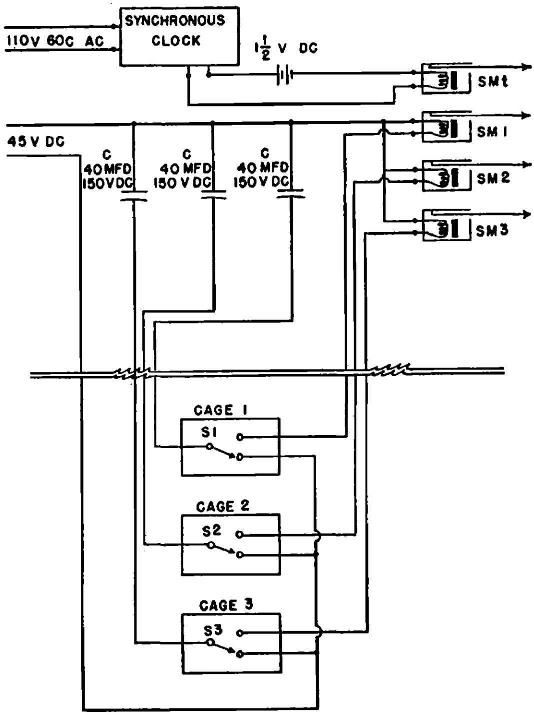

Fig. 3. Schematic diagram of circuits for simultaneous recording from three activity cages.

DETAILS OF THE APPARATUS

On each recording cage (Figure 2) is mounted a reverse-action spring micro-switch (S in figures 1 and 3, Model MXY-1, W. L. Maxon Corporation, New York 1, New York). The adaptor-plate spring normally holds the adaptor plate arm in position 1 closing the capacitor-charging circuit so that the capacitor (40 MFD, 150V DC) is charged in a fraction of a second. An extension (aluminum wire no. 12) of the adaptor-plate arm is attached to a perch suspended in the cage. The weight of the perch is balanced with a weak coil spring (Figure 2) so that the weight of the perch alone will not depress the adaptor-plate arm. The weight of the bird on the perch is sufficient to overcome the tension of the coil spring and to depress the adaptor-plate arm which moves the microswitch from position 1 to position 2 thus simultaneously closing the capacitor-discharging circuit and opening the capacitor-charging circuit. The capacitor (C) then discharges through the signal marker (SM) whose capillary pen inscribes a vertical mark on the moving kymograph paper. When the bird leaves the perch the microswitch returns to position 1, simultaneously closing the capacitor-charging circuit and opening the capacitor-discharging circuit.

Figure 3 is the wiring diagram for simultaneous recording from three cages. An extension of this plan can be used for six or more units. A multiconductor cable has proved very satisfactory for the connection of the experimental cages in an aviary with the recording apparatus (Figure 4) at some distance.

In addition to the specifications listed above, the following observations on equipment are based on our operation of the system.

1. *Kymograph.* We have used continuous feed electric kymographs (Model A70-140, Phipps and Bird, Richmond, Virginia) designed for continuous ink-recording on paper six inches wide. A kymograph using wider paper should be satisfactory and would allow simultaneous recording from more cages. We have found a paper speed of 2.2 centimeters per minute to be satisfactory.

2. *Recording paper.* The most satisfactory recording paper has been found to be a ten-pound roll of light-weight six-inch bleached drug bond wrapping paper. This is more satisfactory and much less expensive than standard kymograph paper. A separate stand (figures 2 and 4) is used to permit a continuous feed of the paper from the stock roll into the kymograph. The roll of paper is carefully centered on a metal axle with the help of single-hole rubber stoppers. To minimize resistance, the axle turns on roller bearings supported by clamps attached to the uprights of the stand. The axle in the kymograph used normally for a supply roll is used as a roller under which the paper passes as it comes from the stock roll. Guides on this axle insure proper feed of the paper into the kymograph. The paper then passes over the idler roller, over the writing table, between the drive rollers, to the take-up roll. To help overcome the weight of the large roll of paper, strips of friction tape may be placed around the contact portions of the drive roller of the kymograph. At a paper speed of 2.2 centimeters per minute, the take-up roll will hold sufficient paper for a 24-hour recording. By cutting the paper between the drive roller and the take-up roller, a 24-hour recording may be removed from the take-up roller without interruption of the record. A ten-pound roll of drug bond paper (six inches wide) will provide recording surface for ten days to two weeks when used at a rate of 2.2 centimeters per minute.

3. *Signal markers.* The horizontal ink-writing signal marker is designed to operate up to frequencies of 60 pulses per second. We have used satisfactorily those manufactured by Phipps and Bird. Several may be clamped to the mounting rod of the kymograph; we have used up to seven in a battery, six for recording from experimental cages and one from the synchronous-clock timer.

4. *Inks.* Satisfactory inks for use in capillary pens can be prepared easily from certain water-soluble dyes. We have had excellent results with a 0.5 percent aqueous solution of methylene blue. Another mixture consisting of 0.5 gram yellowish eosin and 0.5 gram sodium bicarbonate in 100 milliliters of water is also very satisfactory. Each of these preparations should be heated slightly and filtered before using. We regularly use either of these inks for as long as seven days without interruption for cleaning. Especially if the recording apparatus is located in a room with low relative humidity it is necessary to add distilled water to the pen reservoir at approximately every other filling in order to avoid a concentration of the dye by evaporation. We have found these inks to be superior to the commercial inks prepared for capillary pens.

5. *Power source.* We have used three different units. (a) A sufficient number of 1½-volt or 9-volt dry cells in series to provide approximately 45 volts will operate four to six cages for three or four months. (b) A 45-volt B-battery which delivers about 1½ amperes will provide the DC output necessary to obtain recordings from six cages for about two weeks. (c) Actually more satisfactory is a rectified power supply with a rating of about 45 volts DC and an output of about 200 milliamperes operating from a 110-volt 60-cycle AC outlet. We have used such a unit to obtain 12 simultaneous recordings. Each of these three types of power units has been used satisfactorily with the recording apparatus located about 100 yards from the activity cages in an outdoor aviary.

6. *Timer.* Any apparatus which will close a signal-marker circuit at the desired time intervals would be satisfactory. We have used a laboratory model time-marking clock (Phipps and Bird) which is driven by a synchronous motor.

Figure 5 is a reproduction of a section of a simultaneous recording of the activities of six White-crowned Sparrows and 1-minute timing (bottom line). The differences in magnitude of displacement of the verticle lines have no significance with respect to intensity of activity. They merely represent differences in the characteristics of the signal markers.

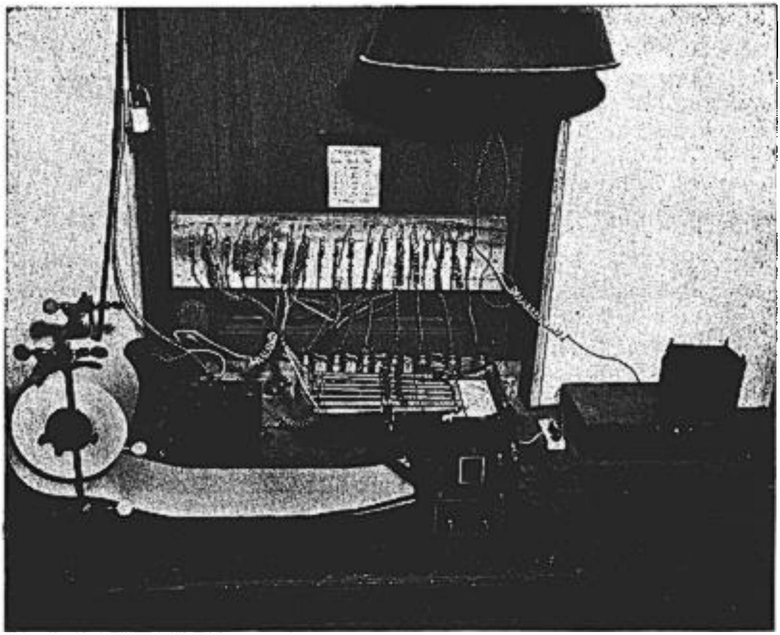

Fig. 4. Unit for simultaneous recording from six cages in an outdoor aviary. The electrical system is an expansion of that shown in Fig. 3.

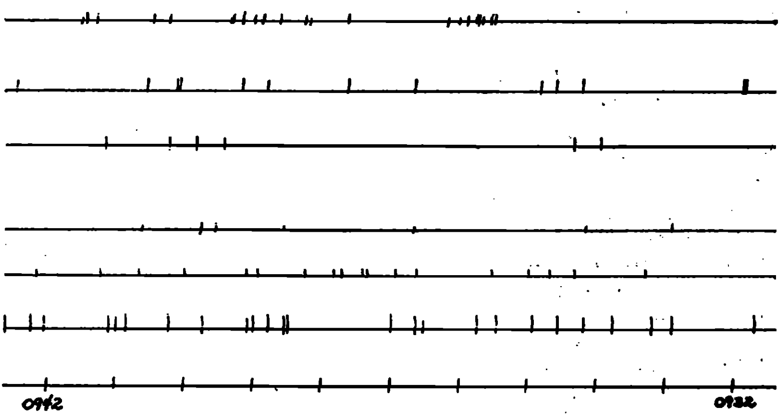

Fig. 5. A ten-minute segment of an actogram of six White-crowned Sparrows. The variable amplitudes of the signals are characteristic of the individual signal markers. The bottom line shows one-minute time signals.

Obviously there are a number of ways in which this recording system could be refined. If the nature of the research problem does not require as precise a record of activity with respect to time, the signal marker in the recording circuit may be replaced with an impulse counter which can be read at desired intervals. We have used satisfactorily, in this respect, Mercury impulse counters (PM 6 V 60 CY, Production Instrument Co., Chicago), by increasing the capacitance (3 dry electrolytic capacitors, 150 MFD 50 V DC 3 V RMS, in series). The impulse counters record up to 99999 before returning to the zero position. It appears practicable to develop a system of relay-operated switches which would throw additional impulse counters into the capacitor-discharging circuit at prescribed intervals, thus reducing the number of times that the counters would have to be read. We have not had such a system in operation, however. It would be desirable further to eliminate the mechanical operation of the microswitches. Possibly this would be practicable with the use of photo-electric relays.

Despite careful attention to the tension of the spring, mounting of the microswitches, and the adjustment of perches, there are small differences in the characteristics of the individual units with respect to their response to a given force on the perch. It is doubtful that these differences in characteristics could be satisfactorily eliminated as long as a mechanical system for operation of the switches is employed. Furthermore, however, individual birds have their individual characteristics with respect to movement in the cage. Two birds may move back and forth in the cage with the same frequency; one strikes the perch with sufficient force during each movement to throw the switch whereas the other may cause the switch to be thrown only for a fraction of the movements. Whereas these characteristics do not make extensive differences in the accuracy of recording we are nevertheless of the opinion that analyses of data should be based primarily on comparison of patterns of activity rather than comparisons of absolute recorded activity. For purposes of graphic presentation of data we use an *index of activity* which is simply rate of recorded movements of the perch per hour. These indices are routinely calculated for half-hour periods except at the beginnings and at the ends of periods of activity.

We have used this system of recording primarily in the investigation of normal and experimentally induced *Zugunruhe* in White-crowned Sparrows, and to a lesser extent in the study of the diurnal activity pattern of Clark Nutcrackers *(Nucifraga columbiana)* under normal and modified photoperiods. Figure 6 shows a record of activity for a White-crowned Sparrow in an outdoor cage for a period of 48 hours during the latter half of April. Figure 7 shows the record for the same bird for 48 hours during the first week in May after *Zugunruhe* had begun. Superficially, at least, these patterns show a considerable degree of similarity with those obtained by Palmgren (1938, 1944b) for the European Robin *(Erithacus rubecula)* in winter and spring. More precise comparisons must await a more thorough analysis of our data. The patterns of activity of the Clark Nutcrackers are of interest in contrast to those of the White-crowned Sparrows because of the complete absence of nocturnal activity. In this respect the record in Figure 8 is typical.

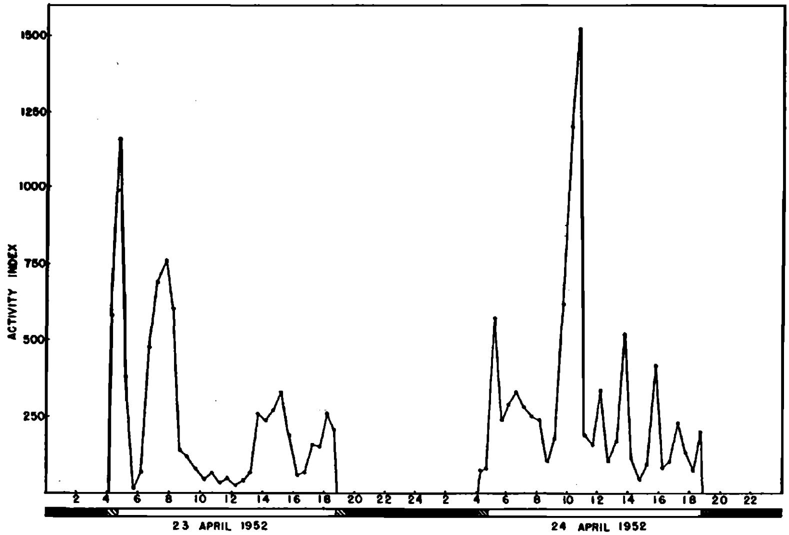

Fig. 6. Forty-eight-hour record of the rate of activity of a first-year male White-crowned Sparrow during prenuptial-like molt just prior to the onset of *Zugunruhe*. At the base of the figure, black bar designates the period of darkness; diagonally hatched bar, civil twilight; and open bar, sunrise to sunset.

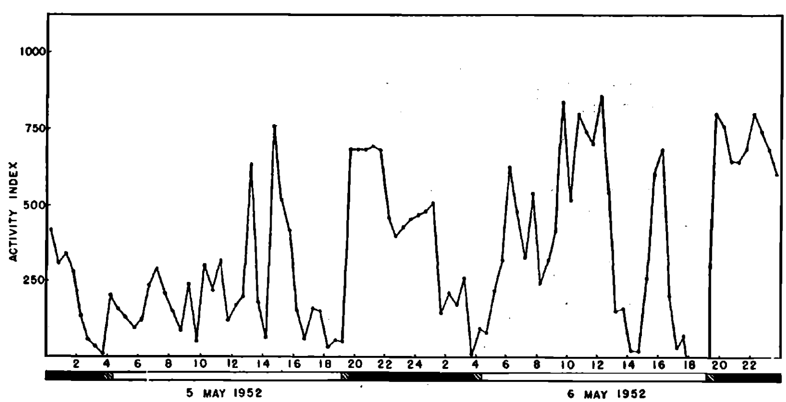

Fig. 7. Forty-eight-hour record of the rate of activity of the bird in Fig. 5 after the completion of molt and after the onset of *Zugunruhe*.

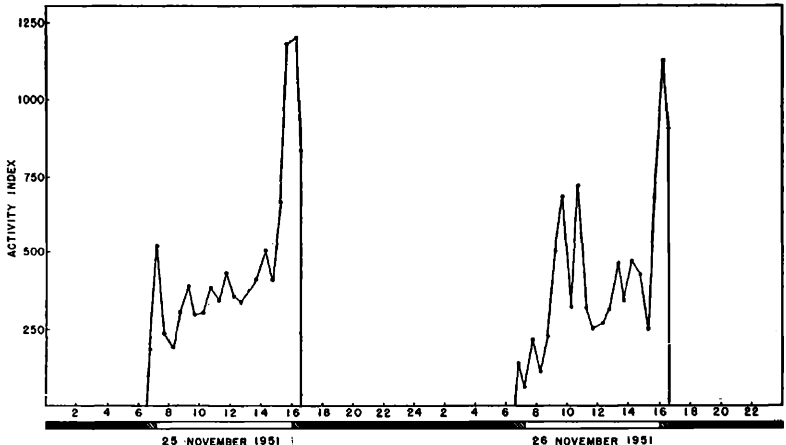

Fig. 8. Forty-eight-hour record of the rate of activity of an adult female Clark Nutcracker. This species has not shown nocturnal activity at any time of the year.

We are indebted to Professor Jerome H. Johnson for invaluable advice concerning the electrical apparatus.

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DANGER OF LEG MUTILATION FROM THE USE OF METAL COLOR BANDS

By PARKER C. REED

Bird banders do not realize the incipient danger in the use of colored metal bands. Where two metal bands are mounted one over the other on the same leg, the lower one will flatten and thicken until it is a hazard to the bird's leg, if not its life.

During the early spring of 1952, when summer residents were returning to the vicinity of our banding station in Lexington, Massachusetts, we first noted an occasional bird with one leg. As we saw more, and gave them our focused attention, we noted that the right foot was missing in all cases. Since we band on the right leg only, we were con-